Homogenizer for Collimated Light with Controlled High Angle Scatter

Technical Field

The present invention relates to efficiently homogenizing collimated light entering a light guide and more specifically to backlighting a liquid crystal display (LCD).

Background of the Invention

It is known that the use of a collimated backlight and a front diffusing screen can greatly improve the quality of an LCD. One such approach is described in Saccomanno (US Patent 6,428,198), which is incorporated herein by reference. Saccomanno describes the use of an arc lamp, whose light is collected, homogenized, and coupled into an array of optical conduits. Each conduit then illuminates a non-imaging optic, which collimates the light and subsequently illuminates the edge of a light-extraction guide.

Even though my prior patent teaches an effective collimated light and diffuser screen arrangement, for certain applications such as medical imaging there is a need to improve black-level contrast and image sharpness even at the expense of a slightly larger and less light efficient device.

SUMMARY OF THE INVENTION

In accordance with my present invention, a mild diffuser, having controlled scattering angles, is placed at the input aperture of a slab light guide. This mild diffuser is inserted between the collimation source (e.g. non-imaging optics) and the light extraction guide. Unlike the diffusers

that have been previously used in diffuse backlights, the diffuser in accordance with my invention has a controlled scattering angle of less than about eight degrees and most advantageously of less than +/- 5 degree full-width half-maximum (FWHM) scatter and is referred to herein as a 'mild diffuser' to contrast it from the prior art diffuser arrangements. The slab light guide further serves to homogenize the collimated beam. The slab light guide may be a separate element from the light extraction guide or the light extraction guide may have a "lead-in" portion that comprises a homogenizing slab section.

This homogenizer technique is especially useful in overcoming irregularities due to periodic structures that supply the source of collimated light. Since any diffuser will naturally increase the overall beam divergence, an optical constraining layer, having a refractive index slightly less than the refractive index of the slab light guide, is positioned on one or more outer surfaces of the slab light guide. A light absorbing black layer is then positioned on the optical constraining layer or layers, the light absorbing layer having a higher refractive index than the slab light guide and the optical constraining layer. The result of this combination is that the slab light guide now can strip out high angle light.

Such high angle light will cause increasing fuzziness between adjacent pixels and also cause a net lowering of the black-level contrast; this effect is described in Yamaguchi (US Patent 6,421,103). The light exiting the slab light guide is thus homogenized and stripped of high-angle light and can be fed into the light extraction guide, providing a uniform output.

Description of the Drawing

FIG. 1 illustrates a homogenizer in accordance with one illustrative embodiment of the present invention.

FIG. 2 illustrates a homogenizer in accordance with my invention in combination with a wedge shaped light extraction guide.

DETAILED DESCRIPTION OF THE INVENTION

Referring first to FIG. 1, an acrylic (although other optical quality materials may be used) slab light guide 12, having a first refractive index, is covered on its top surface 43 with an optical constraining layer 15, such as an acrylic pressure sensitive adhesive (PSA). A type of PSA that is suitable for my invention is Rexam OCAV3. The optical constraining layer 15 has a second refractive index, which is slightly less than the refractive index of the slab light guide 12. In one embodiment of my invention, the acrylic slab light guide 12 has a refractive index of 1.4893 while the optical constraining layer 15 has a refractive index of 1.4800.

Because of the slight difference in refractive index, the optical constraining layer 15 acts to trap light within the light guide under certain conditions. Accordingly, collimated light that enters the acrylic slab light guide 12 at surface 41 through a mild diffuser 11 with an angular spread below a certain threshold value is contained within the slab light guide 12 by total internal reflection (TIR). Light with an angular spread above the threshold value exits the slab light guide 12 and enters the optical constraining layer 15. In embodiments of my invention using PSA as the optical constraining layer 15, it also mechanically functions to adhesively fasten an optical absorbing layer 16, such as for example, Dupont Kapton CB black polyimide, to the slab light guide 12, forming a sandwich structure therewith.

In other embodiments of my invention the optical absorbing layer is disposed on the optical constraining layer, for example, in certain embodiments, the optical constraining layer 15 is a thin film coating on the acrylic slab 12 and the optical absorbing layer is a black paint overcoat, such

as for example Krylon Ultra-Flat or Tetenal Kameralack. Note that the optical constraining layer must be thick enough, for example three wavelengths of light, so that the total internally reflected light is not inadvertently absorbed due to the evanescent aspect of light reaching the black layer.

The optical absorbing layer 16 has a refractive index that is greater than the refractive index of optical constraining layer 15. This difference in refractive indices causes the light within the optical constraining layer 15, that is, the light that has not been contained by TIR within the light guide, to exit into the optical absorbing layer 16 where it is absorbed.

Advantageously, the mild diffuser allows for the mixing of discrete collimated light sources, such as non-imaging collimators 22 that are optically driven from optical fibers 21. Suitable mild diffusers are available from Reflexite (Avon, CT), part numbers BP336, BP302 and BP321 having symmetric half angles of +/-3.9 degrees, +/-3.8 degrees, and +/-2.8 degrees, respectively. From lab testing, it has been determined that BP321 is preferred when used in combination with a "SolarTec CL Light" fiber optic illuminator from Wavien, Inc. (Santa Clarita, CA), ESKA SK60 fibers from Mitsubishi Rayon Co. (Tokyo, Japan), and Poly II acrylic from Polycast (Stamford, CT). In other embodiments of my invention, the mild diffuser 11 is embossed on the entrance aperture of the slab light guide 12.

Light that is angularly limited below the threshold limit passes through the slab light guide 12 and exits at surface 42. Advantageously, this angularly limited collimated light is especially suitable for a wedge light extraction guide 23 as may be found behind a liquid crystal display (LCD).

In certain embodiments of my invention, the lower surface 44 of the slab light guide 12 has a second optical constraining layer 17 and a second optical absorbing layer 18 disposed thereon. These optical layers

function in the same manner as previously described optical constraining layer 15 and optical absorbing layer 16.

Referring now to FIG. 2, there is depicted another illustrative embodiment of the present invention. In this embodiment, the mild diffuser, slab light guide, and wedge light extraction guide are fashioned from the same monolithic substrate 50, preferably acrylic. The monolithic substrate 50 comprises two distinct regions, a constant cross-section slab light guide region 61 and a wedge-shaped light extraction guide region 62. The light enters the slab light guide region 61 through an embossed entrance diffuser 51. Similar to the previous embodiment, the slab light guide region 61 includes an upper surface 53 and a lower surface 54.

The upper surface 53 and the lower surface 54 are covered with optical constraining layers 15 and 17, respectively as in the prior embodiment. The optical constraining layers 15 and 17 each have a second refractive index, which is slightly less than the refractive index of the monolithic substrate 50. Because of the slight difference in refractive index, the optical constraining layers 15 and 17 act to trap light within the slab light guide region 61 under certain conditions. Accordingly, collimated light that enters the monolithic substrate 50 through embossed entrance diffuser 51 with an angular spread below a certain threshold value is contained within the monolithic substrate 50 by total internal reflection (TIR). Light with an angular spread above the threshold value exits the monolithic substrate 50 and enters the optical constraining layers 15 and 17.

Disposed on the optical constraining layers 15 and 17 are optical absorbing layers 16 and 18, respectively. The optical absorbing layers 16 and 18 each have a refractive index that is greater than the refractive index of optical constraining layers 15 and 17. This difference in refractive indices causes the light within the optical constraining layers 15 and 17, that is, the light that has not been contained by TIR within the

monolithic substrate 50, to exit into the optical absorbing layers 16 and 18, where it is absorbed.

Table 1 below details results of the Snell's law calculations for a certain illustrative embodiment of my invention comprising a 6-millimeter thick acrylic slab with a refractive index of 1.4893, and an optical constraining layer formed from a PSA with a refractive index of 1.4800. These calculations detail input light angles from 5 to 23 degrees in air. The calculations show that light with a divergence angle of greater than 10 degrees is absorbed. Also shown in Table 1 is the minimum slab length required for the input light to have at least one reflection into the optical constraining layer. For example, for light having angles 10 degrees and greater to get absorbed the slab length needs to be at least two inches long.

Table 1

Input Light Angle (degrees)	Light Angle within slab (θ) (degrees)	Minimum Slab Length (mm)	Light Angle into PSA (degrees)
5.0000	3.3549	102.36	TIR
6.0000	4.0247	85.28	TIR
7.0000	4.6938	73.08	TIR
8.0000	5.3620	63.93	TIR
9.0000	6.0294	56.81	TIR
10.000	6.6958	51.11	88.049
11.000	7.3610	46.45	86.367
12.000	8.0249	42.56	85.157
13.000	8.6875	39.27	84.120
14.000	9.3486	36.45	83.177
15.000	10.008	34.00	82.295
16.000	10.666	31.86	81.455
17.000	11.322	29.97	80.646
18.000	11.976	28.29	79.861
19.000	12.627	26.79	79.096
20.000	13.277	25.43	78.347
21.000	13.924	24.21	77.612
22.000	14.568	23.09	76.889
23.000	15.210	22.07	76.176

Alternate Embodiments

Alternate embodiments may be devised without departing from the spirit or the scope of the invention. For example, an array of collimated light emitting diodes (LED) or low numerical aperture fibers can be ass input sources in lieu of the non-imaging collimated light sources comprising collimators 22 and optical fibers 23. Also, the light guides need not be solid, but can be hollow by use of TIR films, such as that described in Whitehead (US Patent 4,260,220).